Cu-8 Cr-4 Nb Alloy Database Development For The Reusable Launch Vehicle (RLV)

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Outline

- **Application and History**
- **Chemistries**
- **Powder Analysis**
- **Consolidation**
- **Thermophysical Testing**
- **Future Testing**

Rocket Engine Thrust Cell Liner

MSFC Produced VPS Cu-8 Cr-4 Nb
Liner Prior To Close-out

- **Thrust cell liners contain the combustion of hydrogen and oxygen in the engine**
- **Flame temperature is approximately 2760ºC (5000ºF)**
- **Liners are actively cooled with cryogenic hydrogen**
- **Thickness of cooling channel wall is typically near 1 mm (0.040”)**
- **Material subjected to extreme thermal gradients and heat fluxes**

History

- Original Development at NASA Glenn Research Center (GRC)
  - Powder lots produced by Special Metals in 1990 and 1992
  - Material properties were greatly superior to NARloy-Z (Cu-3 Ag-0.5 Zr)
    - Exception was somewhat lower thermal conductivity
- Reusable Launch Vehicle (RLV) NRA 8-21 Awarded June 1998
  - Develop database for Cu-8 Cr-4 Nb powder produced by Crucible Research
- Crucible Research Production Runs
  - Three sets of runs have been made
    - First two for Rocketdyne Division of Boeing
    - Third set of runs for NASA GRC and Marshall Space Flight Center (MSFC)
      - Seven runs for GRC each producing ~125 pounds of powder
      - Four runs for MSFC each producing ~125 pounds of powder

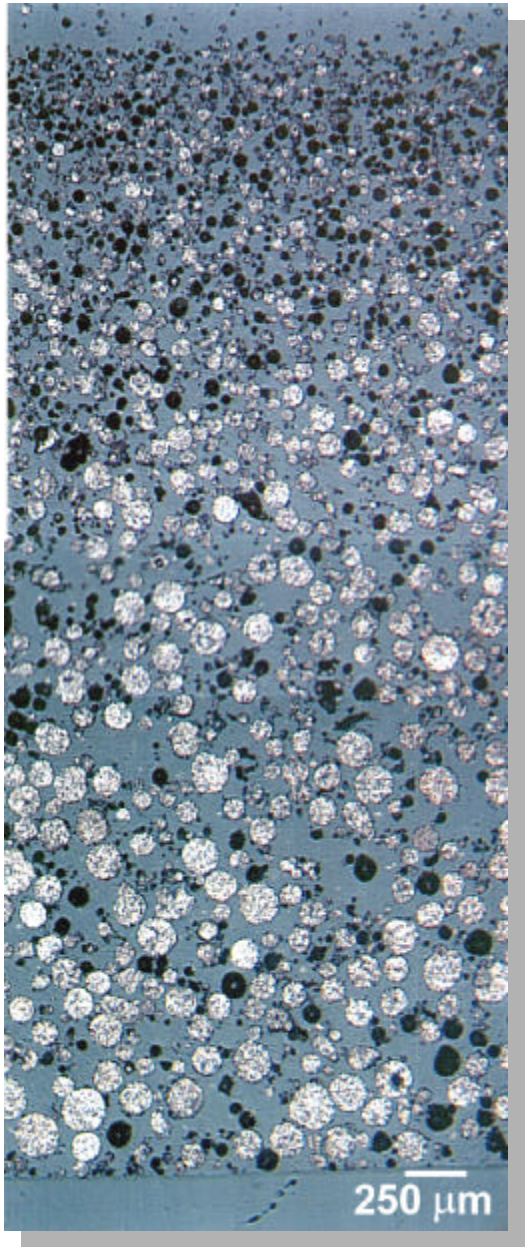
Cu-8 Cr-4 Nb Powder Chemistries

	Cr		Nb		Cr:Nb Ratio		Cr+Nb		Calculated	O
Powder Lot	**wt.%**	**at.%**	**wt.%**	**at.%**	**wt.%**	**at.%**	**wt.%**	**at.%**	**Cr_2Nb vol.%**	**ppm**
3A	6.80	8.34	5.93	4.07	1.15	2.05	12.73	12.41	14.55	732
3B	6.52	8.00	5.81	3.99	1.12	2.01	12.33	11.99	14.10	711
3C	6.72	8.24	5.89	4.04	1.14	2.04	12.61	12.29	14.42	471
3D	6.78	8.32	5.98	4.11	1.13	2.03	12.76	12.42	14.59	626
3E	6.79	8.33	5.99	4.11	1.13	2.03	12.78	12.44	14.23	476
Special Metals	6.45	7.91	5.79	3.98	1.11	1.99	12.24	11.89	14.00	455
Average	6.72	8.25	5.92	4.06	1.13	2.03	12.64	12.31	14.38	603.2
Std. Dev.	0.12	0.14	0.07	0.05	0.01	0.02	0.19	0.19	0.21	124.9
Minimum	6.52	8.00	5.81	3.99	1.12	2.01	12.33	11.99	14.10	471.0
Maximum	6.80	8.34	5.99	4.11	1.15	2.05	12.78	12.44	14.59	732.0

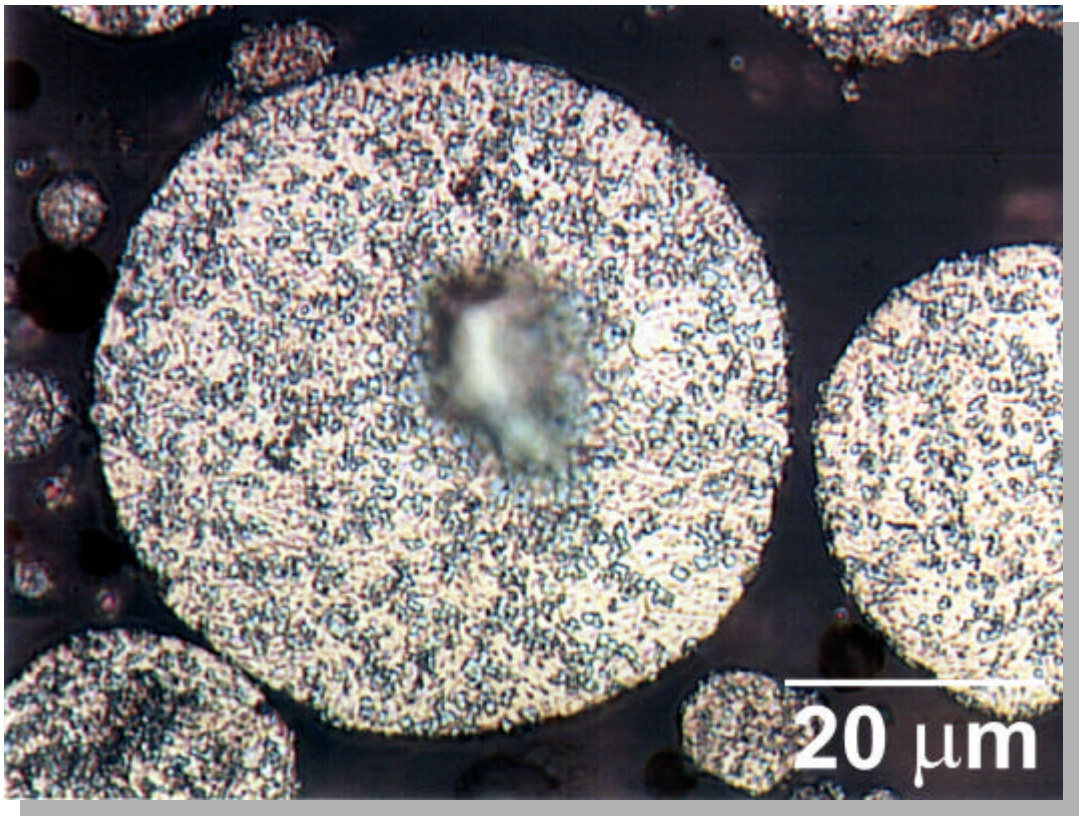
Statistics apply only to the five Crucible Research Cu-8 Cr-4 Nb powder lots

Calculated volume percent Cr_2Nb uses FCC phase for Cr_2Nb and assumes all Cr and Nb used

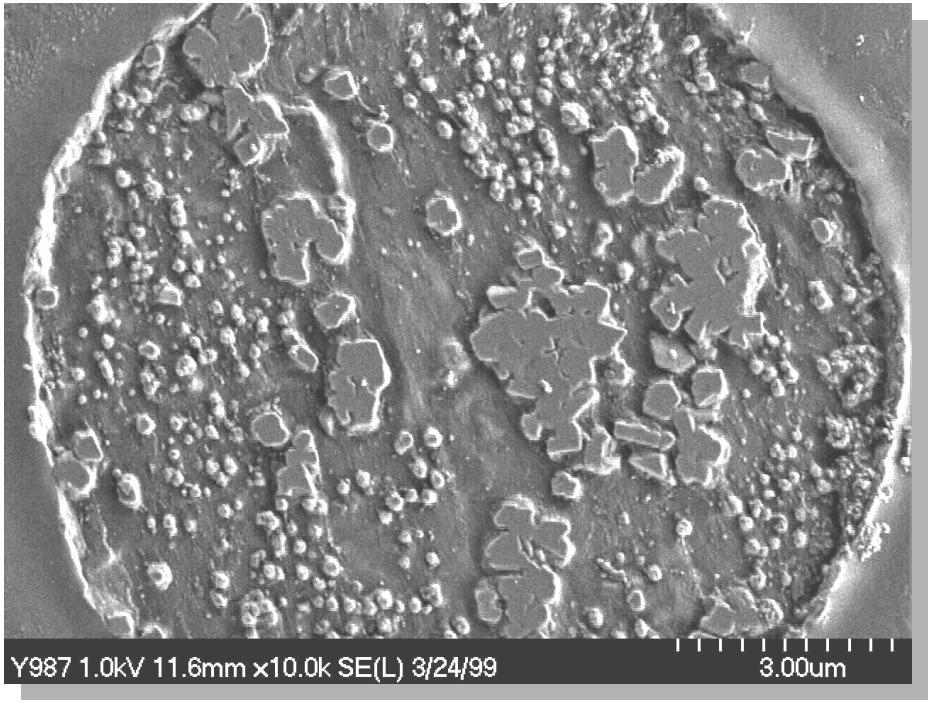
Optical Micrograph of Powder Particles



- Powder particles are spherical with few satellites
- Voids are present within many particles
  - Believed to be solidification shrinkage rather than trapped Ar

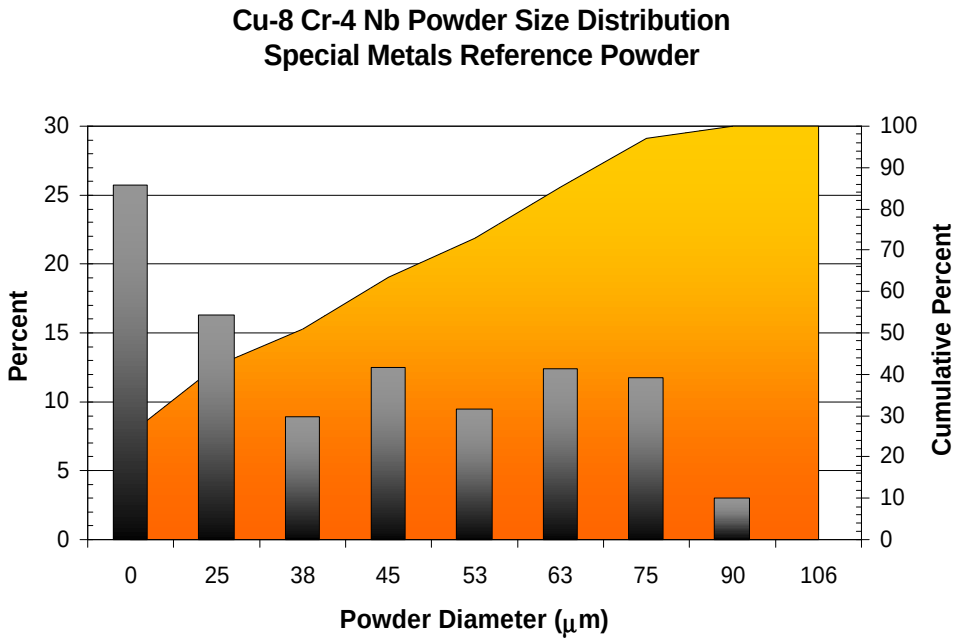


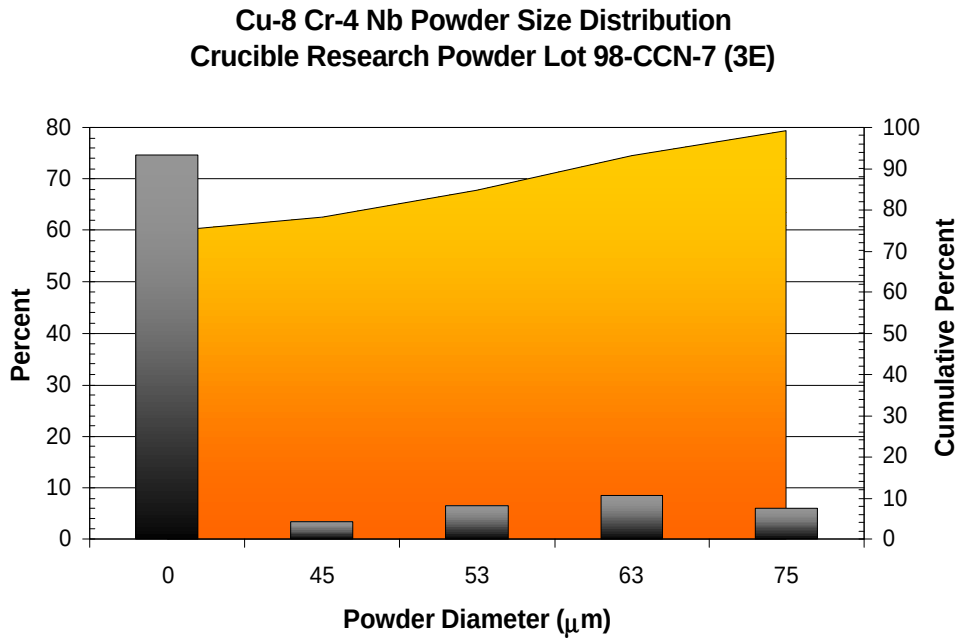
Cr_2Nb Precipitates In Cu-8 Cr-4 Nb Powder



- Cr_2Nb particles appear to be agglomeration of individual precipitates
  - Cr_2Nb forms in liquid prior to Cu solidification and agglomerates
  - Consistent with Special Metals powders

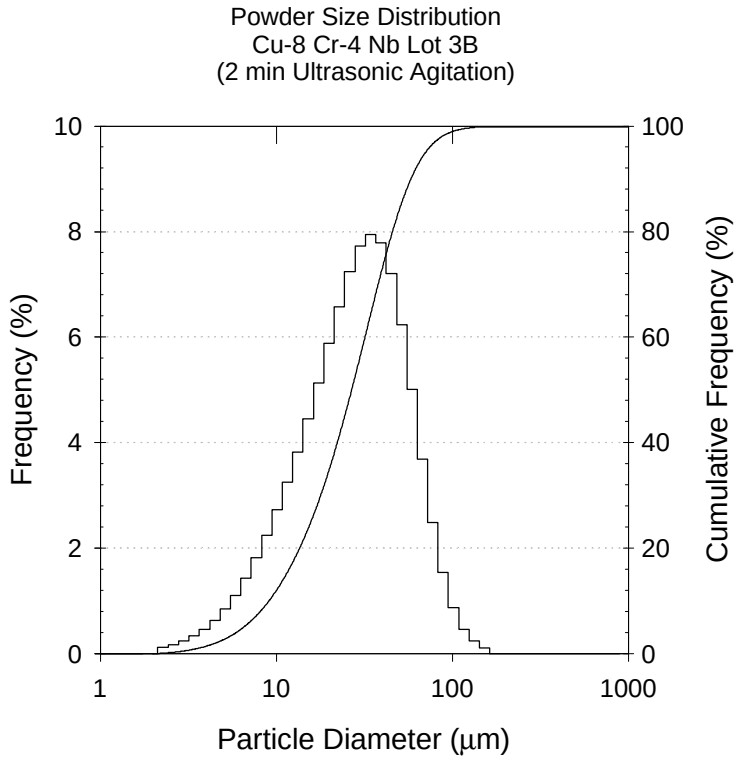
Powder Size Analysis - Sieve Analysis





- **Powder sieved to -150 mesh (<106 μm) to remove any coarse particles**
- **Over 70% of Crucible Research powder was -325 mesh (<44.5 μm) vs. 50% for Special Metals powder**

Powder Size Analysis - Horiba Particle Size Analyzer



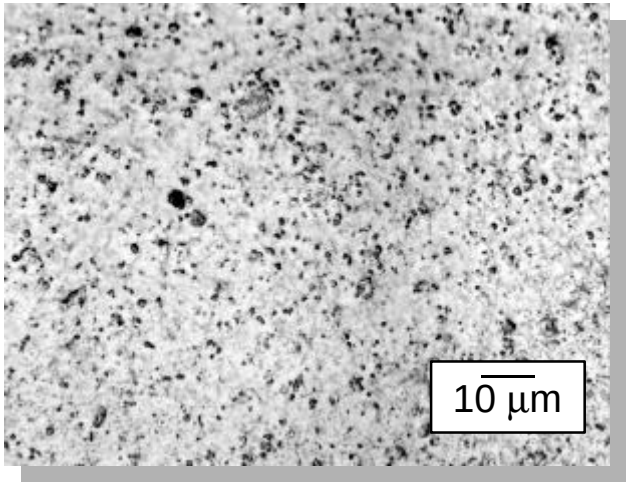
Powder Lot	Mean Particle Size (μm)
3B	30.265 (σ=22.393)
3C	41.949 (σ = 30.638)
3D	42.784 (σ = 33.816)
3E	36.294 (σ = 29.650)

- **Testing conducted at Ricerca using a Horiba LS-900 particle size analyzer**
  - **Unit capable of simultaneously measuring from 0.05 μm to 1020 μm diameter particles**
- **No powder was available for powder lot 3A**

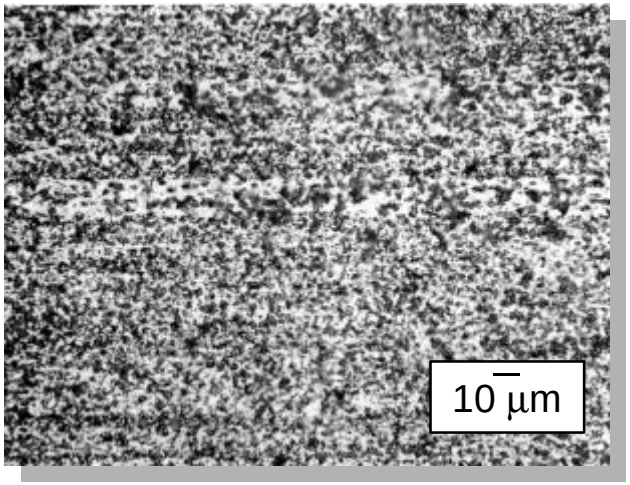
Extrusion

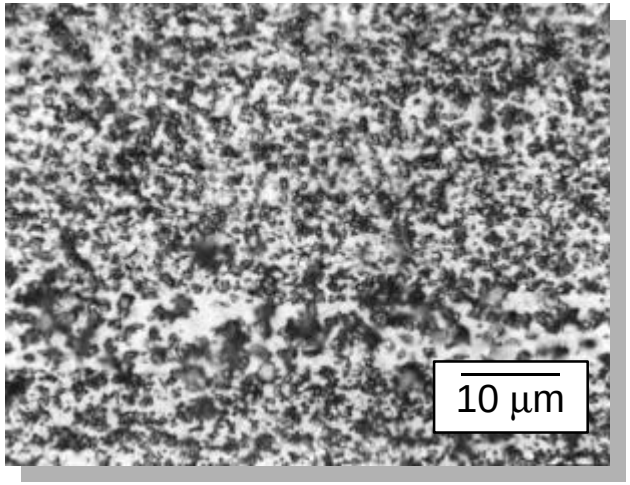
- **Extrusions conducted at CSM Industries, Coldwater, MI**
- **X-ray pole figures showed minimal [111] texture and no [100] texture**

Optical Micrographs Of Extruded Cu-8 Cr-4 Nb



Transverse to extrusion direction

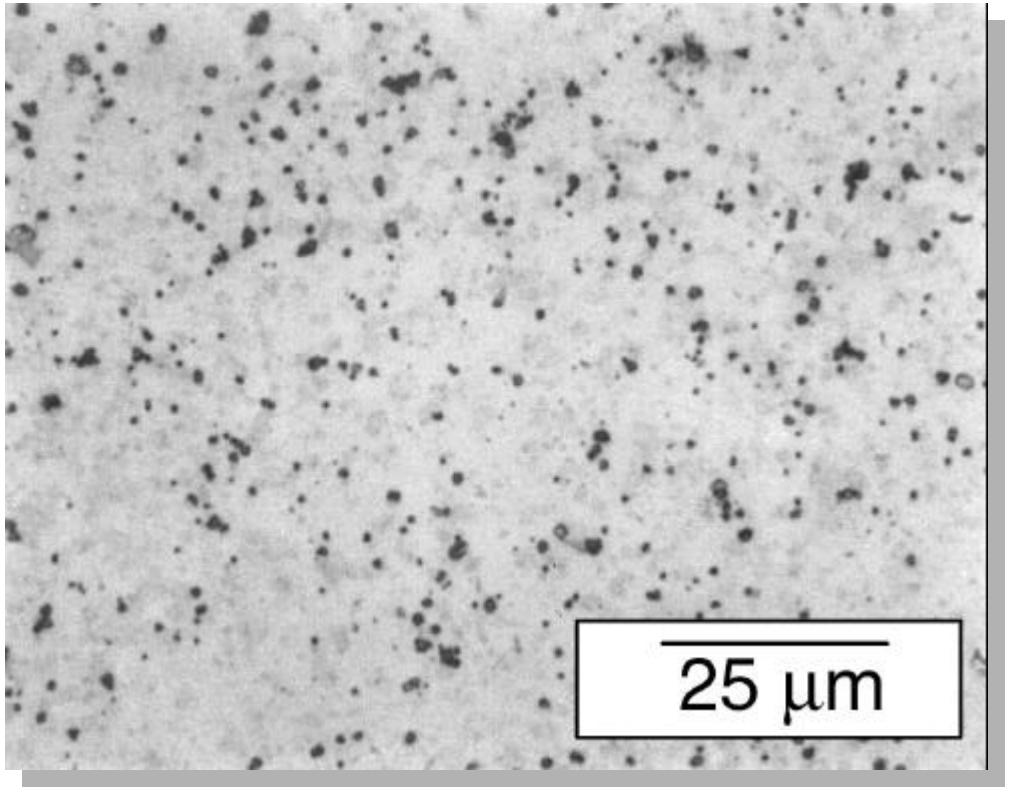




Longitudinal to extrusion direction

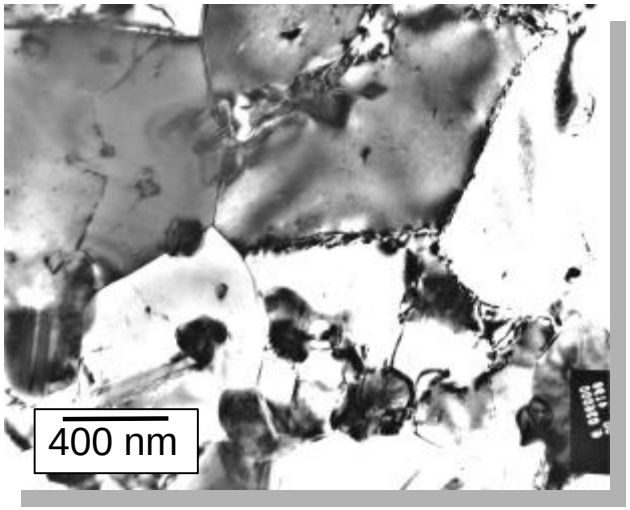
- Electropolishing reveals precipitates in relief extremely well
- Copper grain size may be too fine for optical microscopy
- Possible recrystallized grains observed in longitudinal cross-sections where precipitate volume fraction is locally low
- Electropolishing techniques are still under development
  - Precipitates appear to be redepositing from electrolytic solution
  - Apparent volume fraction of Cr_2Nb precipitates is higher than real volume fraction

Hot Isostatic Pressing (HIPing)

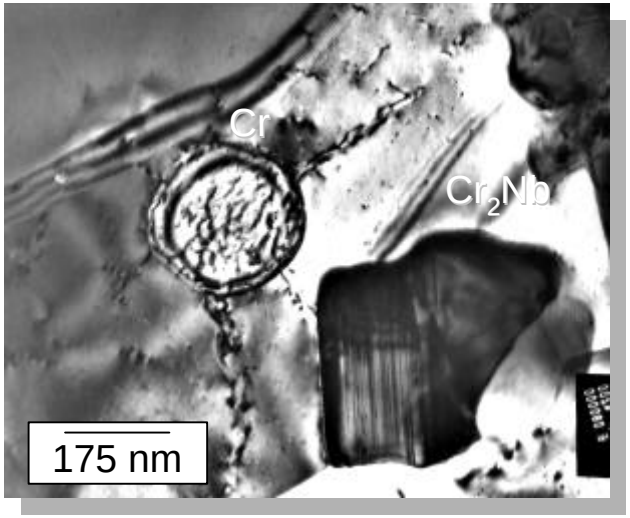


- Samples HIPed at 955°C (1750°F) to minimize Cr_2Nb coarsening
- Full consolidation appears to have been achieved
  - Density measurements will be run on samples after machining

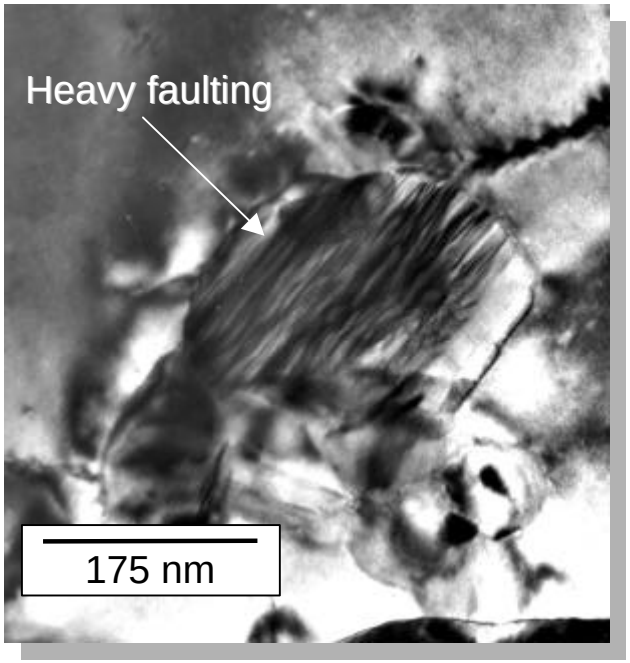
Transmission Electron Micrographs Of Extruded Cu-8 Cr-4 Nb



General Microstructure



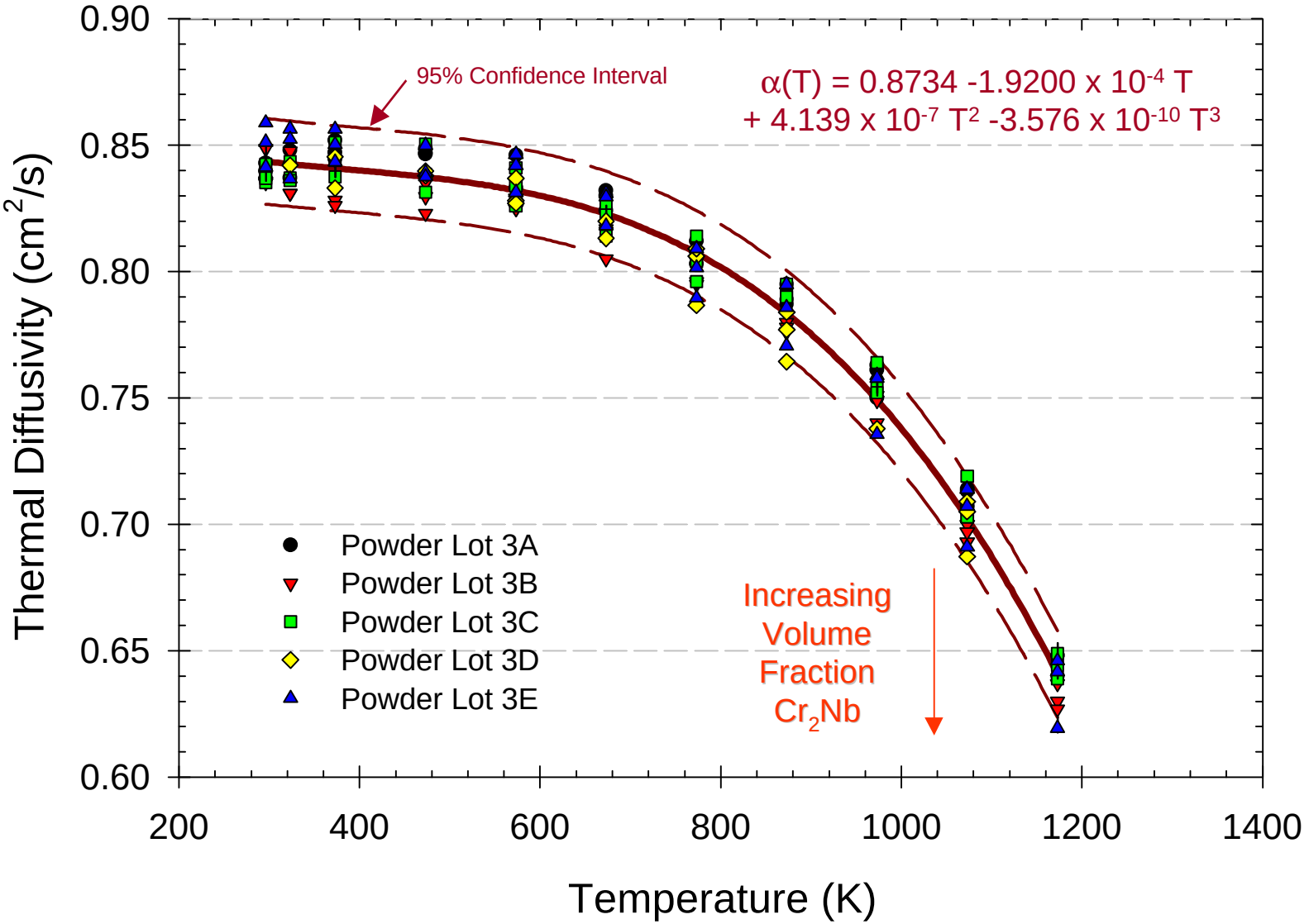
Cr and Cr_2Nb Precipitates



Faulting in Cr_2Nb

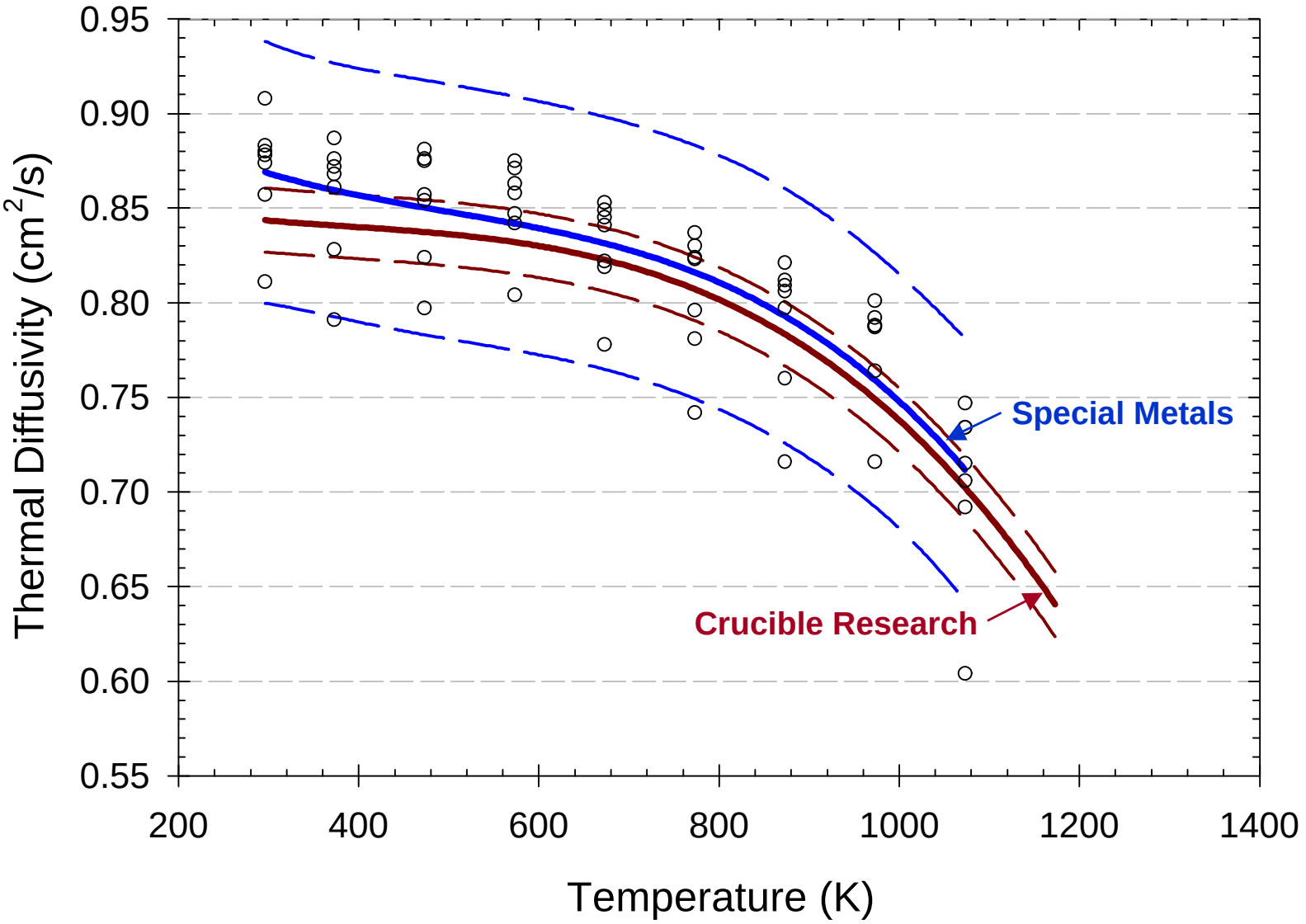
- **Cr_2Nb and Cr precipitates identified**
- **Cr_2Nb precipitates have a very faulted structure**
- **Cr_2Nb range from 150 to 850 nm**
- **HIP samples have nearly identical microstructures**

Cu-8 Cr-4 Nb Thermal Diffusivity

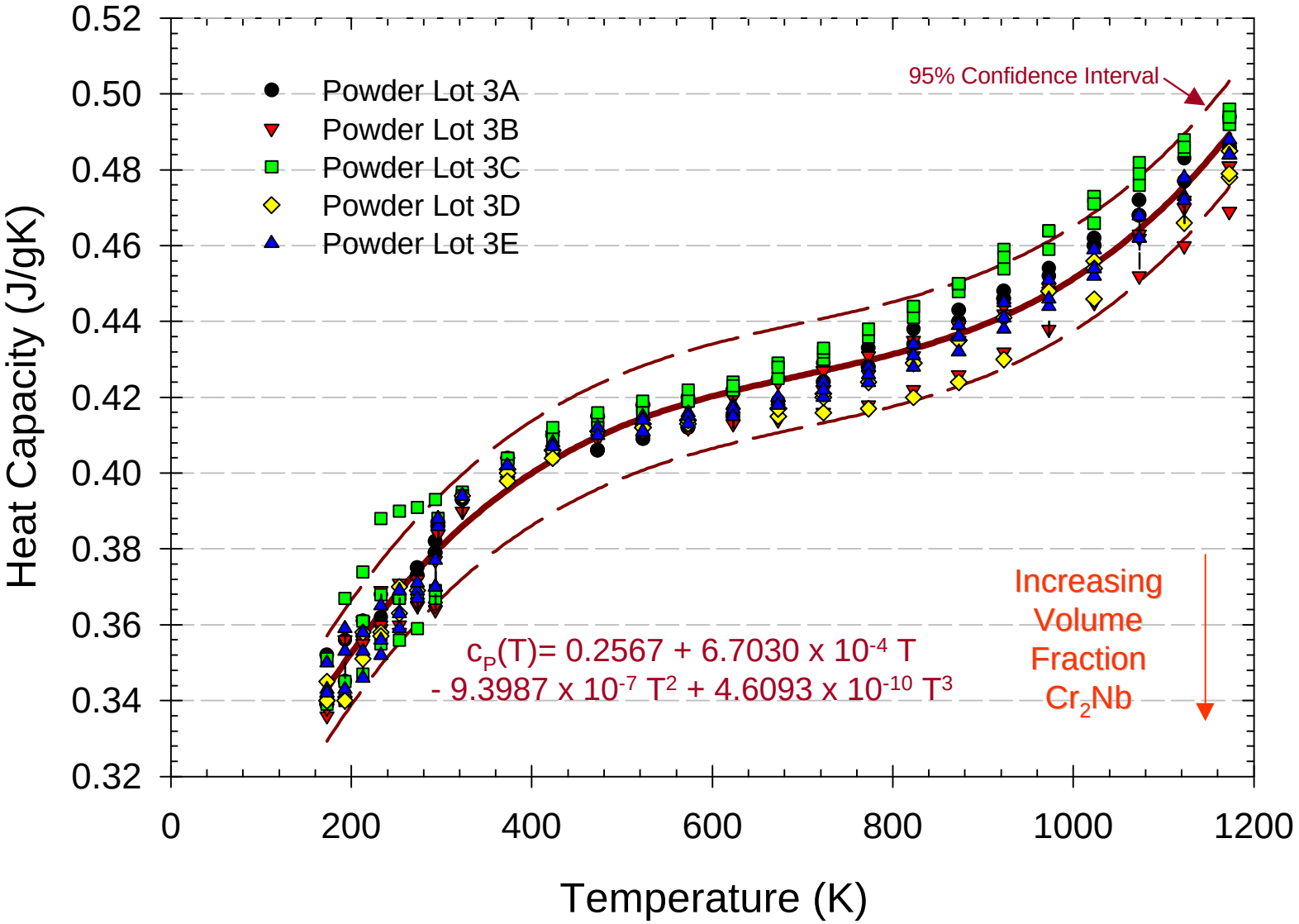


Statistical analysis did not show any discernable lot-to-lot variations in thermal diffusivity

Comparison of Crucible and Special Metals Cu-8 Cr-4 Nb Thermal Diffusivities

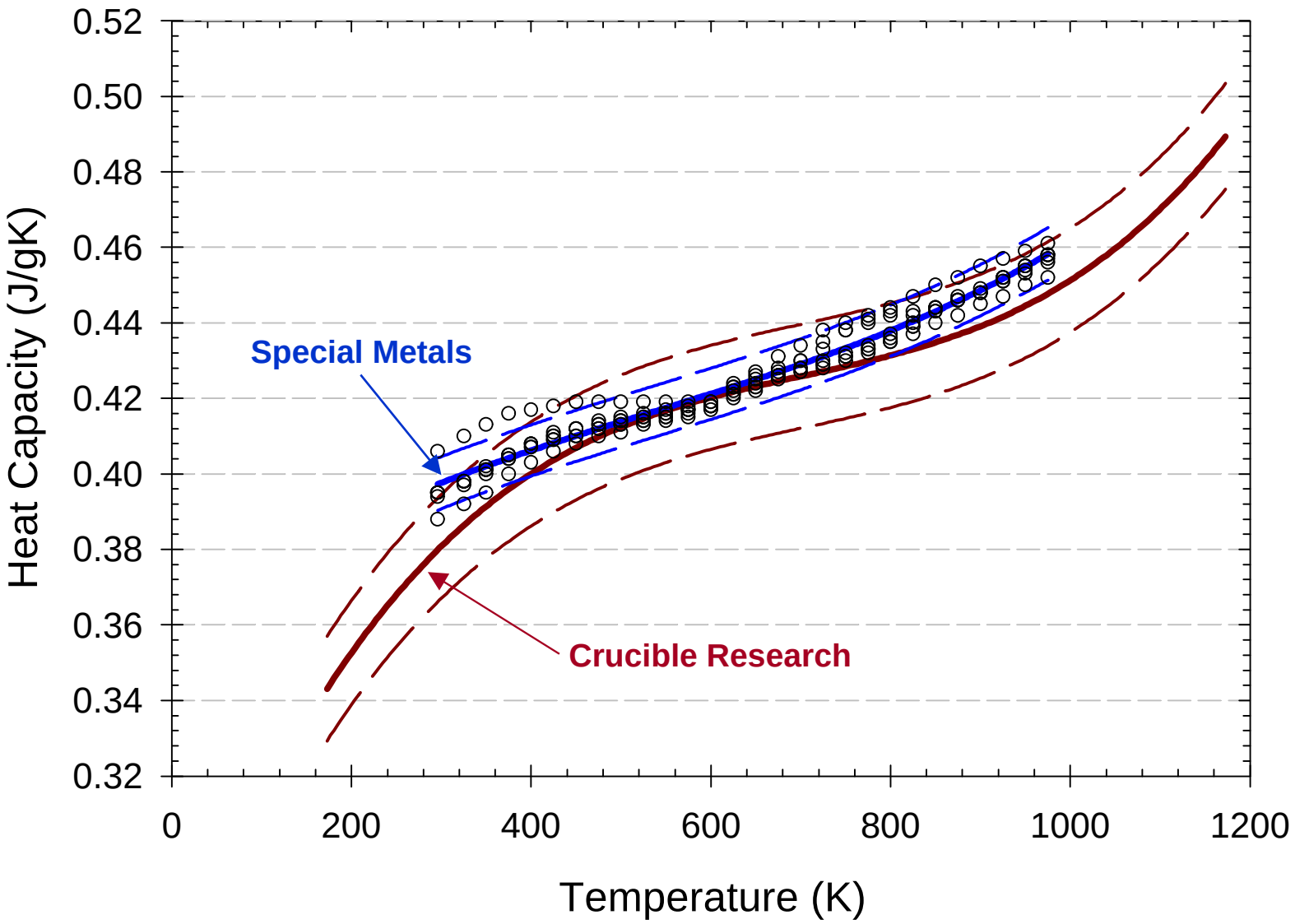


Cu-8 Cr-4 Nb Heat Capacity

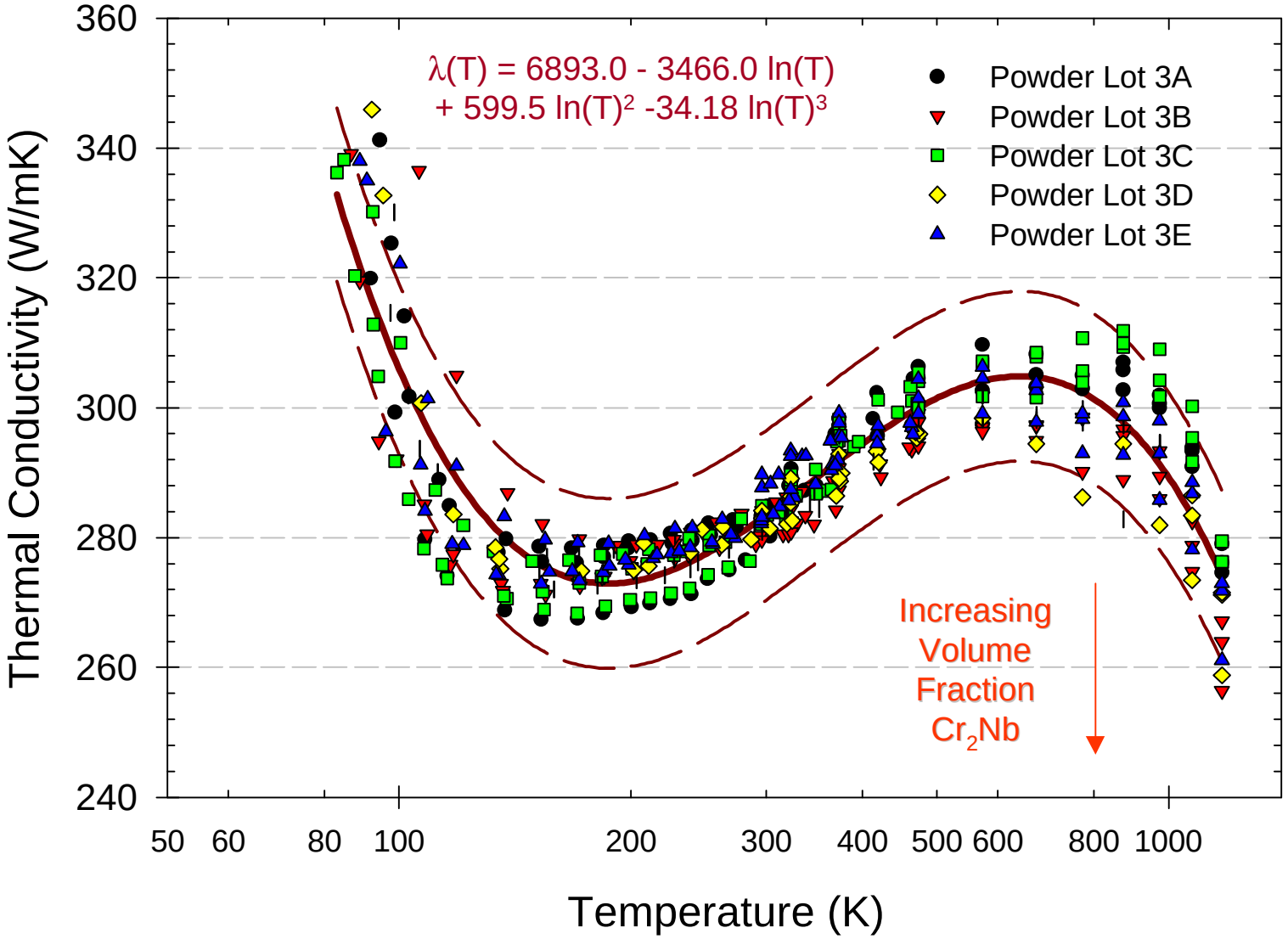


Statistical analysis of elevated temperature heat capacities indicates lot-to-lot variations in heat capacity

Comparison of Crucible and Special Metals Cu-8 Cr-4 Nb Heat Capacities

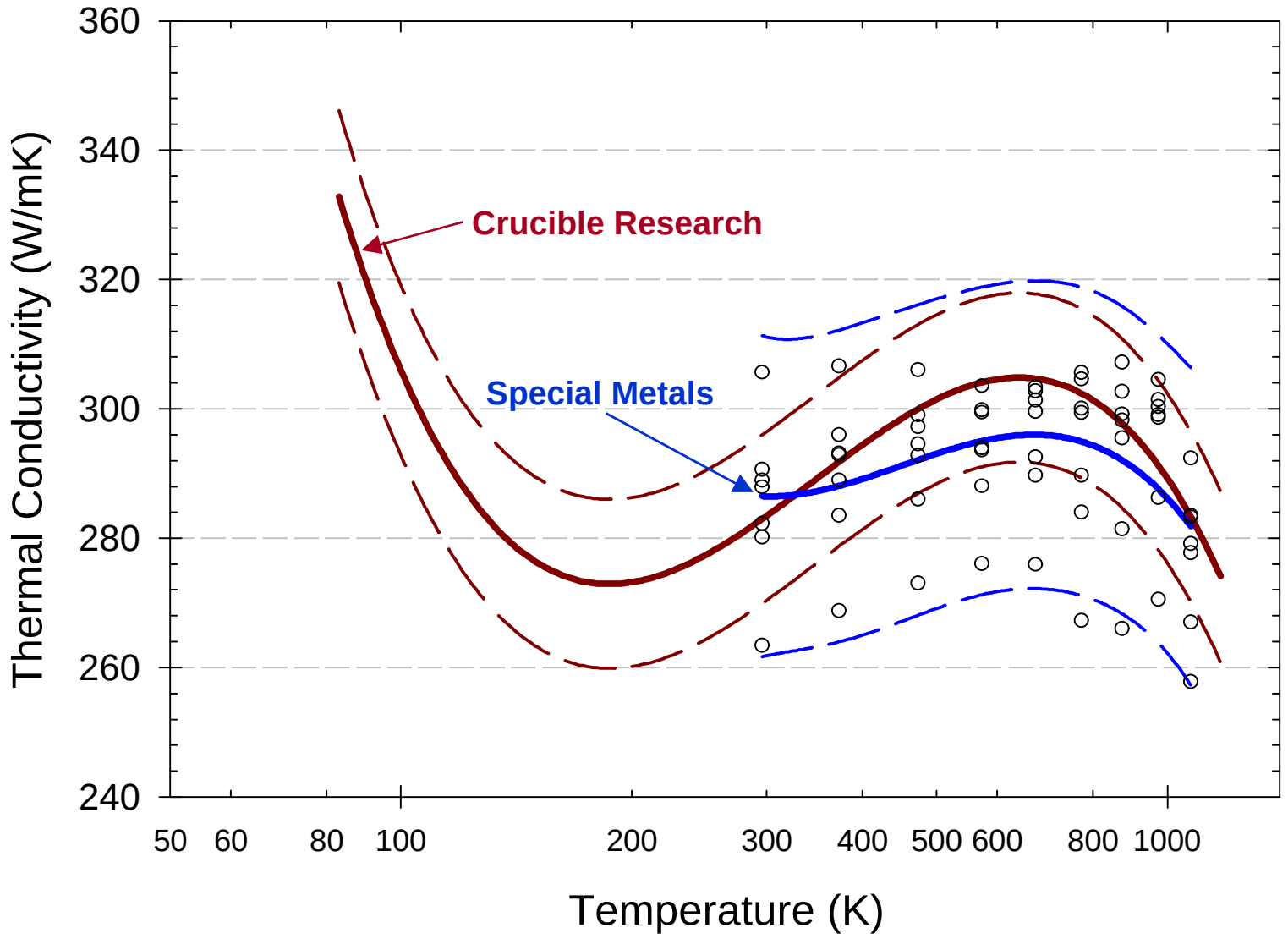


Cu-8 Cr-4 Nb Thermal Conductivity

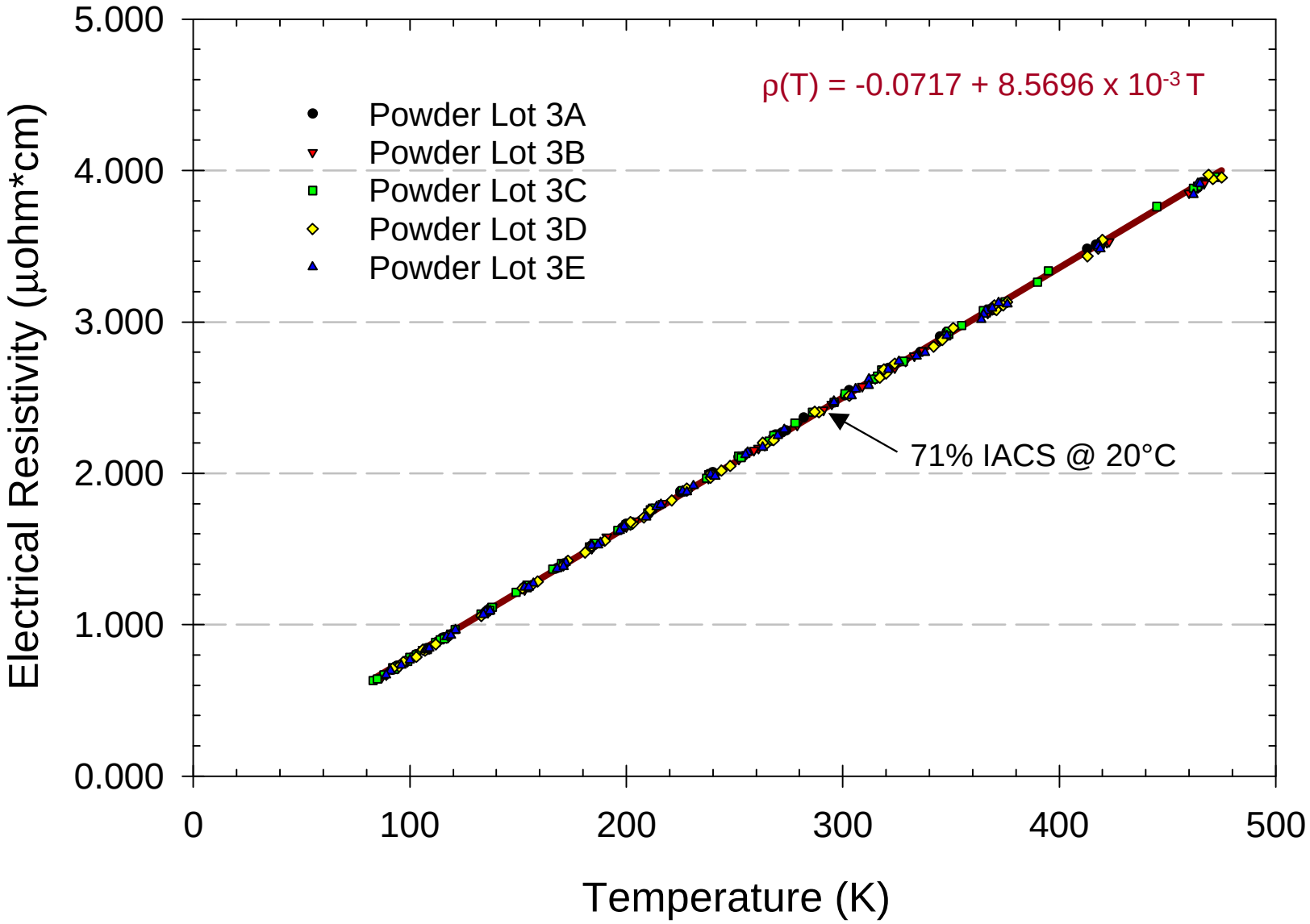


Statistical analysis of elevated temperature thermal conductivities indicates lot-to-lot variations in thermal conductivity

Comparison of Crucible and Special Metals Cu-8 Cr-4 Nb Thermal Conductivities

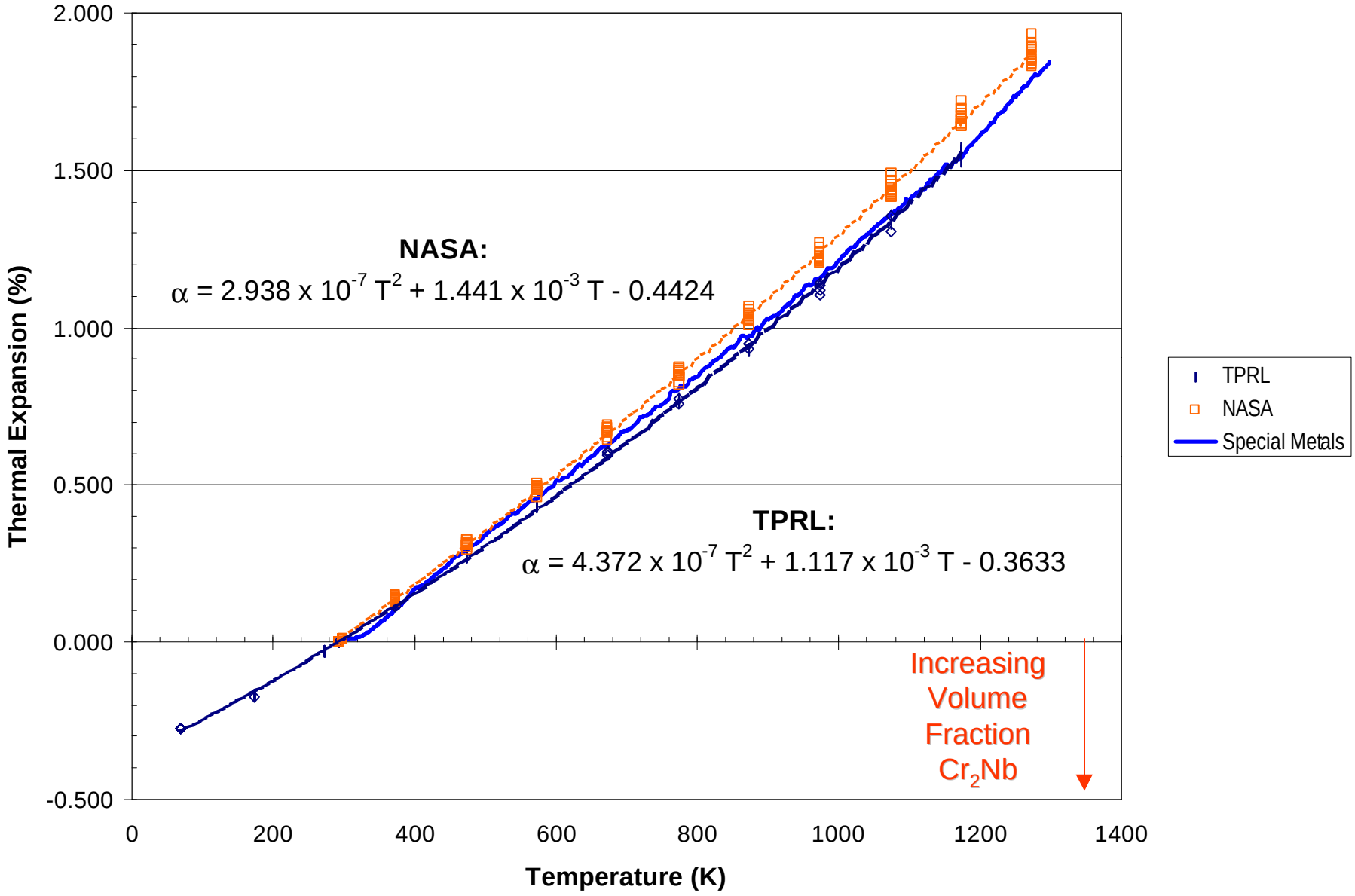


Cu-8 Cr-4 Nb Electrical Resistivity



No discernable lot-to-lot variations in electrical resistivity

Cu-8 Cr-4 Nb Thermal Expansion



Current and Future Work

- Tensile Testing
  - Cryogenic tensile testing at MSFC completed
  - Tensile testing between room temperature and 800ºC currently being conducted
- Creep Testing
  - Short term (50 h max.) creep tests between 500ºC and 800ºC are currently being conducted
- Low Cycle Fatigue (LCF) Testing
  - Room temperature endurance limit of 0.5% strain range has been established in preliminary testing
  - Testing between room temperature and 400ºC with 0.7% and 2% strain ranges is being started
- Fractography and Quantitative Microscopy
  - Fractography and related microscopy to be conducted as samples are tested
  - Quantitative microscopy to determine volume fractions of Cr_2Nb, Cr_2Nb size distributions and copper grain sizes will be done

Further Information

Further information as it becomes available can be found at:

polly.grc.nasa.gov/MDWeb/People/MSELLIS.html